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Design of 5 mm Copper Tube Heat Exchangers for Display Cabinets with R404A

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Introduction

Historically, tube diameter has been coming down:

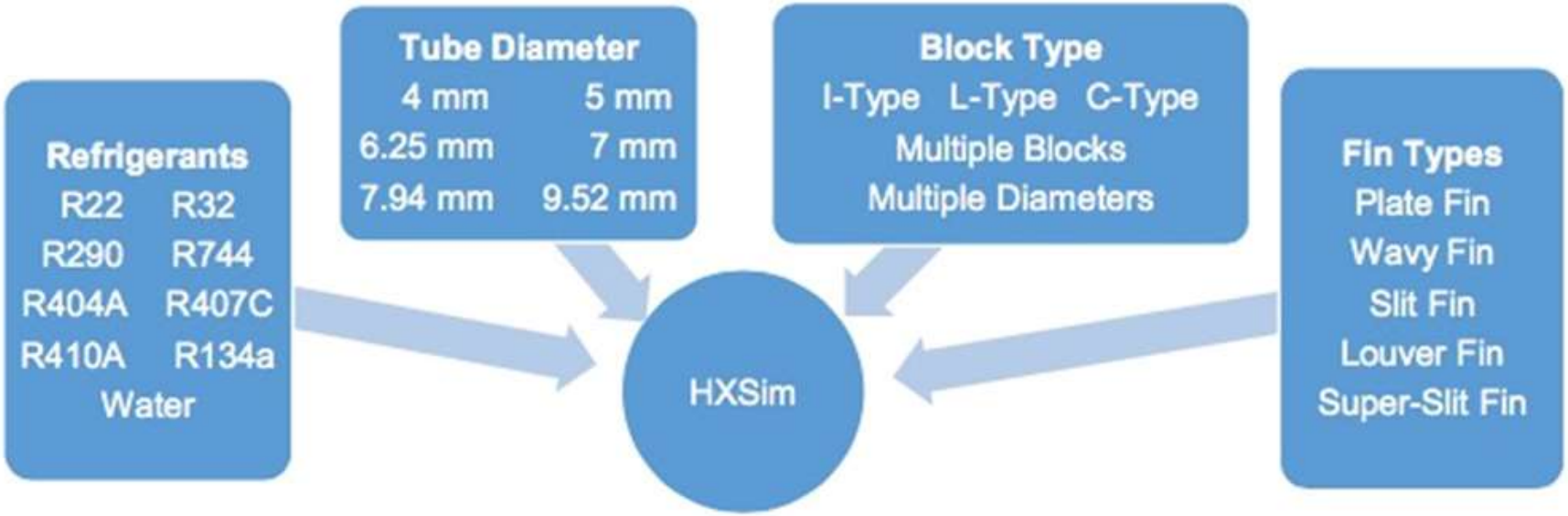
- Smaller diameter copper tubes reduce charge, wall thickness, weight and cost
- HTC increases but also pressure drop (dP) increases
- Increase number of circuits to manage dP

Goal for display cabinet condenser:

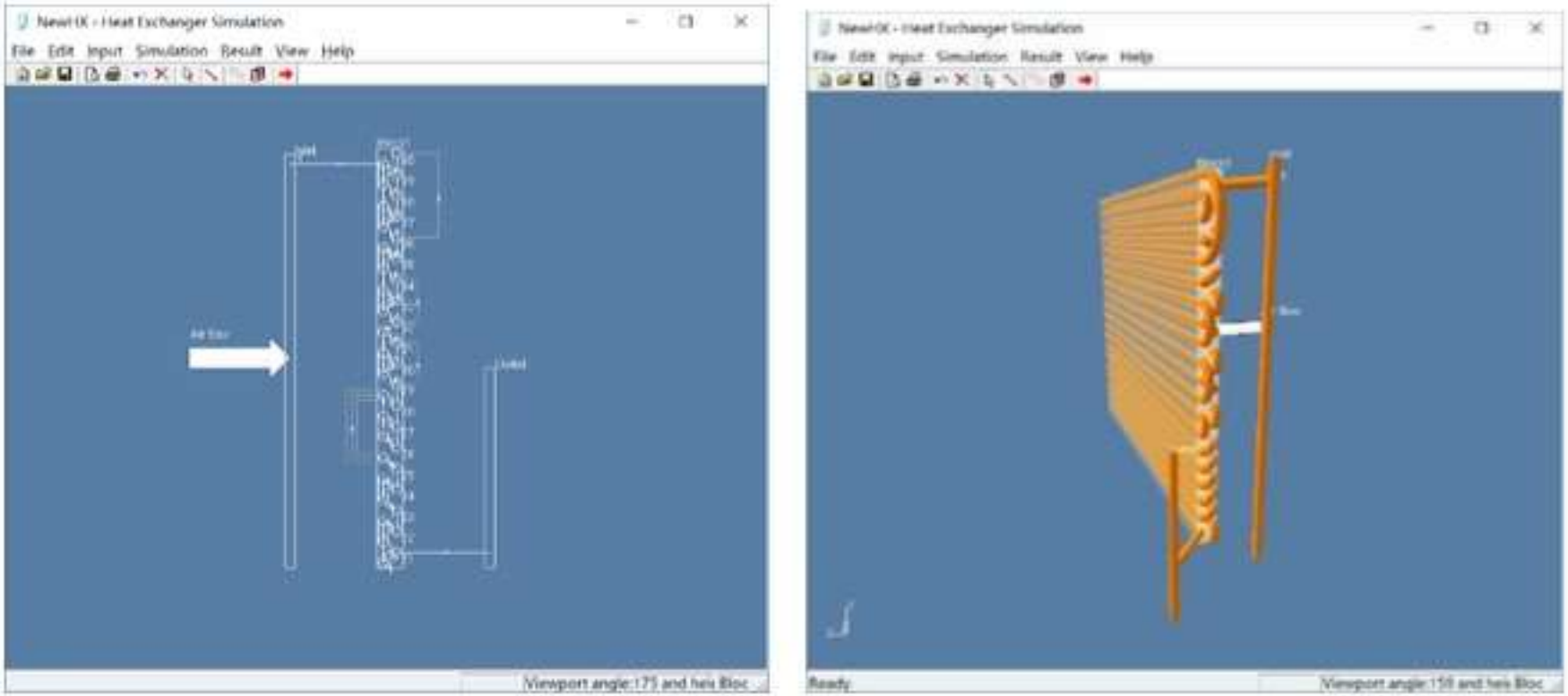
- Replace 9.52 mm (3/8”) tubes with 5 mm tubes
- Maintain heat transfer capacity
- Use HXSim simulation software

HXSim Simulation Software

HXSim simulation software uses empirical correlations for a wide variety of fin designs and internally enhanced tubes. The designer can choose the feature to be varied and select from an extensive list of types of fins and tubes.

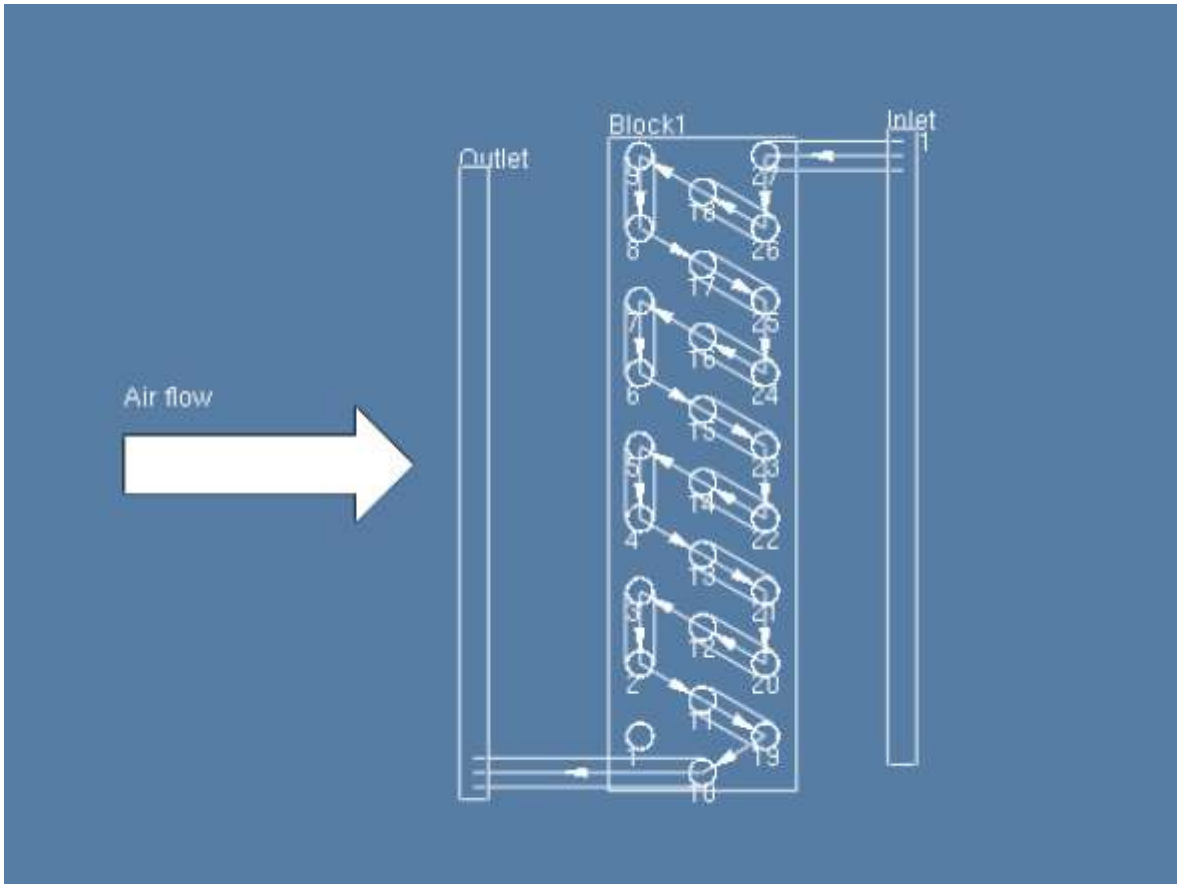


HXSim Simulation Software



HXSim graphical design example in 2-D and 3-D

Original Condenser (9.52 mm)



Parameter	Original Condenser (∅ 9.52 mm)
Single length	450 mm
Tube diameter	9.52 mm
The column spacing	21.65 mm
Row spacing	25 mm
# of tubes	26

Original Condenser (9.52 mm)

Input Parameter	Original Condenser (⌀ 9.52 mm)
Working medium	R404A
Air speed	2.89 m/s
Air inlet dry bulb temperature	25 ℃
Relative humidity of air inlet	60%
The atmospheric pressure	101.3 kPa
Refrigerant inlet pressure	1815.7 kPa
Refrigerant flow	0.028 kg/s

Simulation Results	Original Condenser (⌀ 9.52 mm)
Air outlet temperature	31 ℃
Heat exchange in the condenser	2.247 kW
Refrigerant pressure drop	41.96 kPa
Air side pressure drop	48.52 Pa

Design Principles

$$\Delta P_m{}'' = \frac{C}{d_i^{4.75}}$$

If the tube lengths and flow structure are held constant, replacing 9.52 mm diameter copper tubes with 5 mm copper tubes, will increase the pressure drop by 21.3 times. New tube pattern is required.

Design Principles

The condensers with 5 mm diameter tubes are designed according to the following principles:

1. Countercurrent heat transfer between the condenser refrigerant and the outside air is adopted to improve the logarithmic average temperature difference and enhance heat transfer.

2. The inlet of the condenser circuit is located higher than the outlet to avoid the adverse effect of gravity on the heat exchanger.

(continued next slide)

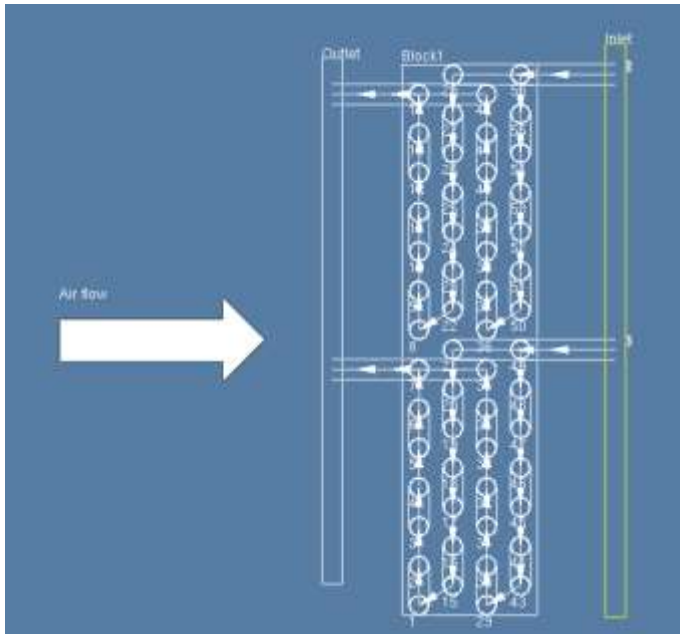
Design Principles

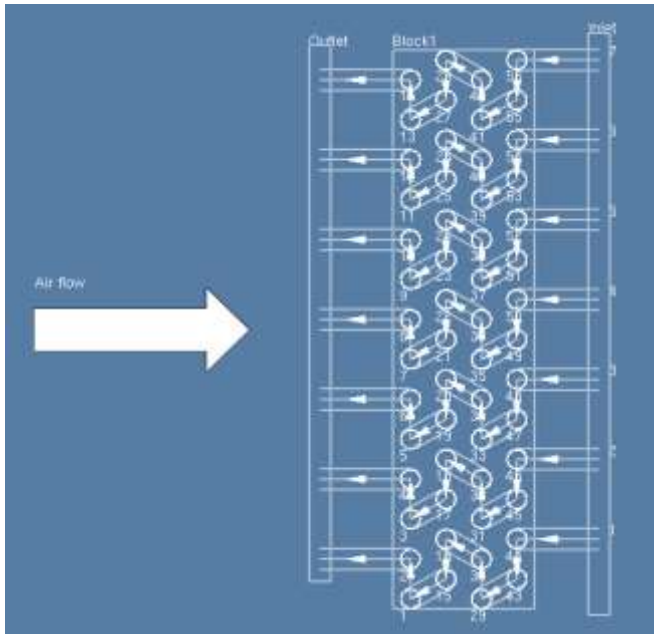
3. Entrances of different paths are placed close to each other; exits also are placed close to each other but as far away as possible from entrances. Losses of heat transfer efficiency from reheating thereby can be avoided.

4. The different tube lengths of the path should be kept the same, to ensure uniform heat transfer of different channels.

5. Tubes can be parallel on the second half of the condenser circuit to improve overall heat transfer uniformity and meet the transfer and pressure drop performance requirements.

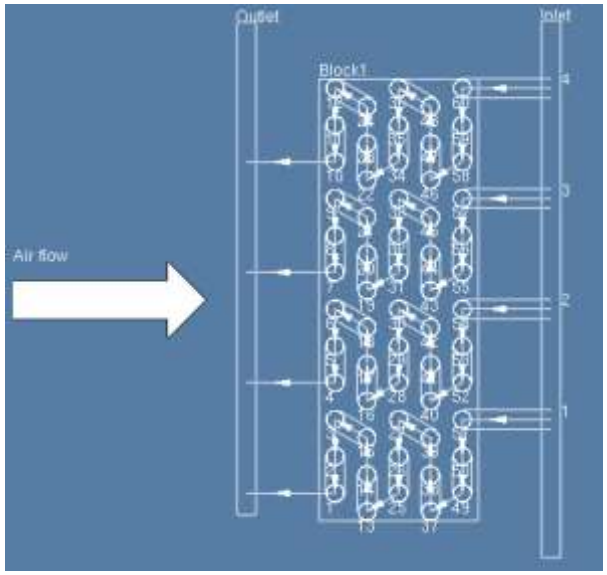
A-Series Simulation (5 mm, 14 x 4)

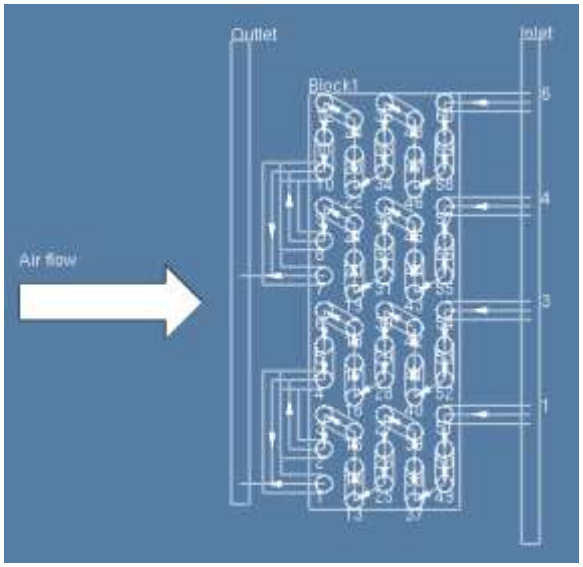


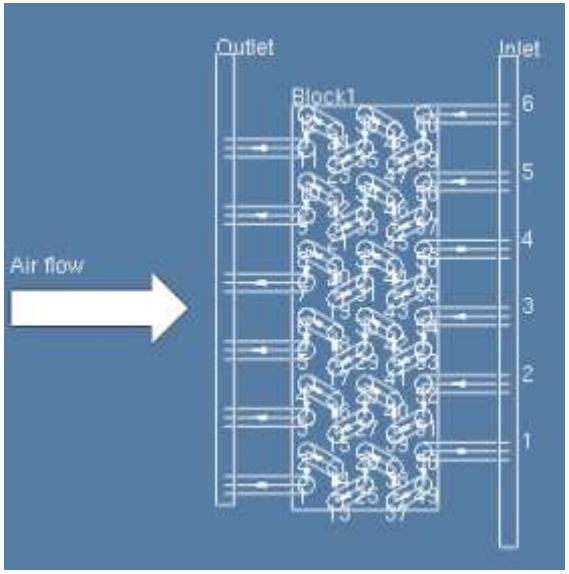


Parameter	⌀ 9.52 mm	A1	A2
Single tube length (mm)	450	450	450
Air outlet temperature (℃)	31	32.4	32.16
Heat exchange in the condenser (kW)	2.247	2.843	2.768
Refrigerant pressure drop (kPa)	41.96	27.64	5.49

B-Series Simulation (5 mm, 12 x 5)

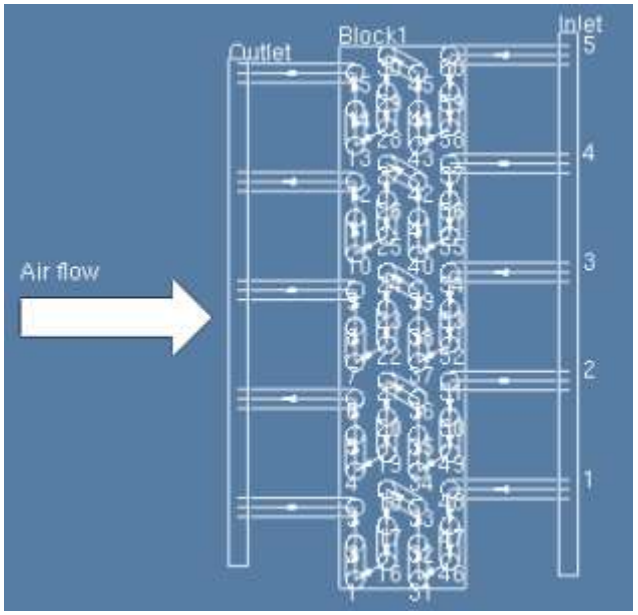


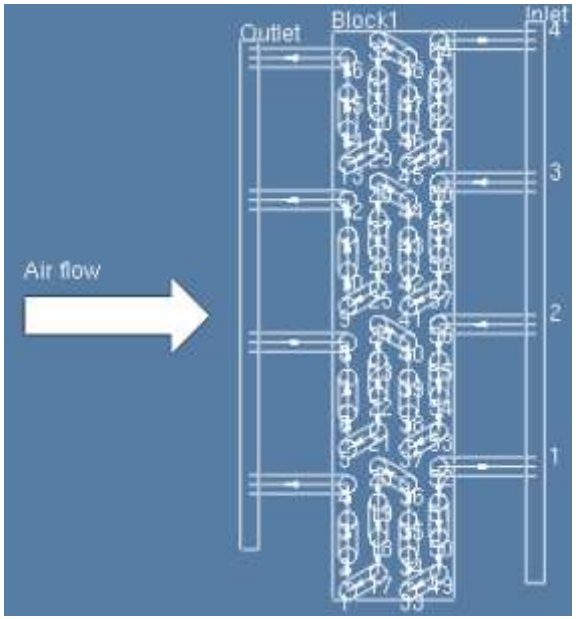


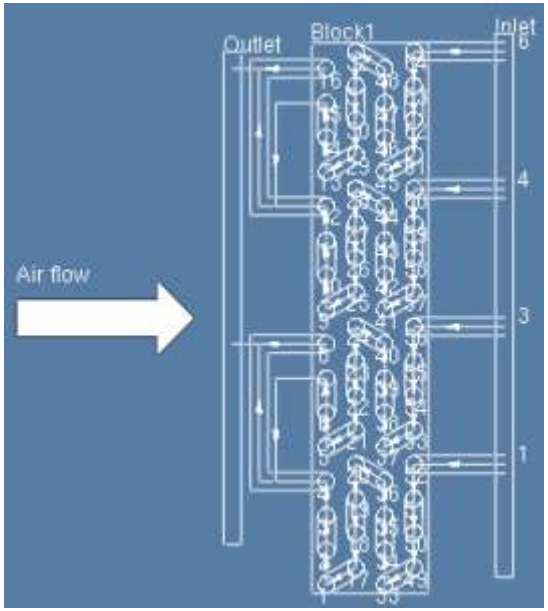


Parameter	⌀ 9.52 mm	B1	B2	B3
Single tube length (mm)	450	450	450	450
Air outlet temperature (℃)	31	33.15	33.19	32.78
Heat exchange in the condenser (kW)	2.247	3.058	3.071	2.921
Refrigerant pressure drop (kPa)	41.96	29.82	32.46	9.13

C-Series Simulation (15, 16, 16) x 4

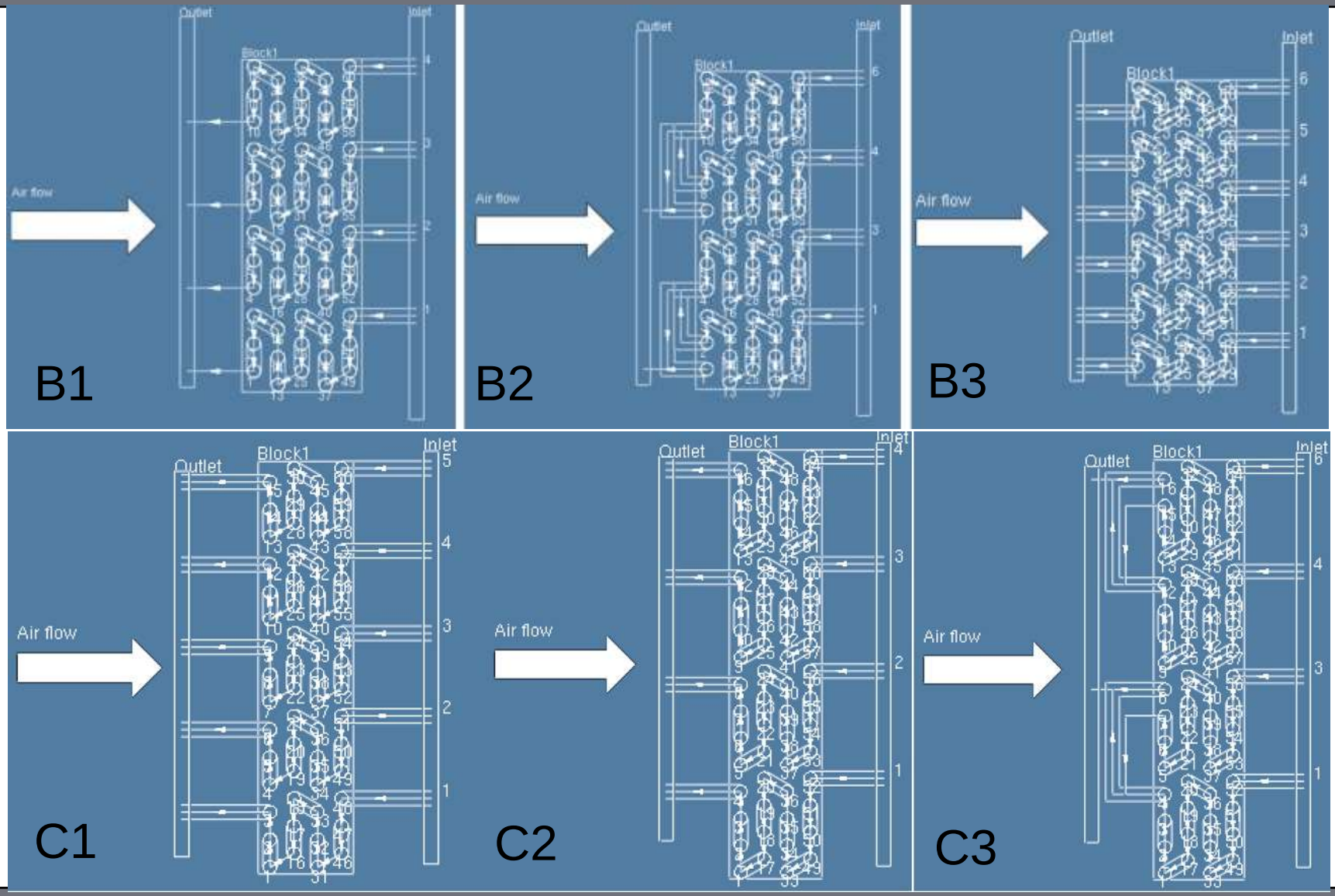






Parameter	⌀ 9.52 mm	C1	C2	C3
Single tube length (mm)	450	420	420	420
Air outlet temperature (℃)	31	33	33.19	32.78
Heat exchange in the condenser (kW)	2.247	3.000	3.052	3.063
Refrigerant pressure drop (kPa)	41.96	15.56	30.18	32.41

Circuits Summary



Simulation Results Comparison

Simulation Results	A1	A2	B1	B2	B3	C1	C2	C3
Single tube length (mm)	450	450	450	450	450	420	420	420
Heat transfer capacity (kW)	2.848	2.768	3.058	3.071	2.921	3.000	3.052	3.063
Refrigerant pressure drop (kPa)	27.64	5.49	29.82	32.46	9.13	15.56	30.18	32.41
Heat transfer area (m^2)	5.88	5.88	6.3	6.3	6.3	6.3	6.27	6.27
Heat transfer per unit area (W/m^2)	483.6	470.8	485.4	487.5	463.7	476.2	486.8	488.6
Pressure drop per unit area (kPa/m^2)	4.7	0.93	4.73	5.15	1.45	2.47	4.81	5.17

Build and Test Prototypes

Photographs of C1 Prototype with sixty 5 mm copper tubes of 420 mm length in four rows.

C1 and C3 System Test results

Original（9.52 mm）									environment temperature
No.	Date	Refrigerant Charge（R404A）	setting temperature（℃）	Compressor exhaust temperature（℃）	Temperature of expansion valve outlet（℃）	low pressure（kgf）	high pressure（kgf）	Average temperature in the cabinet（℃）	25℃ 60%
1	4.15	0.7kg	3	50.1	-8.8	3.4	16.4	8.75	
C1									environment temperature
No.	Date	Refrigerant Charge（R404A）	setting temperature（℃）	Compressor exhaust temperature（℃）	Temperature of expansion valve outlet（℃）	low pressure（kgf）	high pressure（kgf）	Average temperature in the cabinet（℃）	25℃ 60%
1	3.28	0.6kg	2	35.7	-7.1	3.91	14.8	6.6	
2	4.09	0.6kg	0	35.71	-6.83	3.2	14.9	6.25	
3	4.10	0.6kg	2	37.38	-7.24	3.22	14.9	6.68	
C3									environment temperature
No.	Date	Refrigerant Charge（R404A）	setting temperature（℃）	Compressor exhaust temperature（℃）	Temperature of expansion valve outlet（℃）	low pressure（kgf）	high pressure（kgf）	Average temperature in the cabinet（℃）	25℃ 60%
1	5.9	0.6kg	2	39.97	-7.61	3.22	14.9	6.85	
2	5.10	0.6kg	2	39.53	-7.32	3.21	14.8	6.96	

Summary

1. Theoretical design principles were used in the development of eight preliminary designs.
2. All eight models had between 27 and 37% higher capacity compared to the original condenser.
3. All eight models had a lower refrigerant pressure drop compared to the original condenser, a consequence of using multiple paths.
4. Actual heat exchangers were built and laboratory testing was performed on these condensers. They were also tested in the complete system.

Summary *(cont.)*

5. Charge was reduced from 700 g to 600 g for the four systems using smaller-diameter tubes (60 x 5 mm) in the condensers compared to the original system with fewer larger-diameter tubes (26 x 9.52 mm)
6. In other systems using Natural Refrigerants like R290 and R600a, reducing the refrigerant charge is desirable.

References

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Available for download at no charge via **www.microgroove.net/hxsim:**

- Four New Reports from USST (see above).
- HXSim Software (full working version).
- HXSim User manual.

Special Note

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